ADAPTIVE VECTOR MODULATION METHOD AND SYSTEM

FIELD OF THE INVENTION

In general, the present invention relates to the field of communication systems. More specifically, the present invention relates to multi-antenna transceivers and links within wireless systems.

BACKGROUND OF THE INVENTION

Prior art wireless communication systems such as 2nd and 3rd generation cellular systems (e.g., ETSI GSM, TIA IS-95, 3GPP UMTS, etc.) and wireless local area network systems (e.g., IEEE 802.11b) are generally capable of sustaining maximum information bit rates of approximately 20Mbps or less. Future applications for extremely high speed personal wireless communication links anticipate information bit rates well above 100Mbps. Further, the personal (and possibly wearable) nature of the services anticipated to be supported by such links require extremely low-power operation, and therefore minimal complexity in baseband signal processing (including demodulation and error correction stages).

The present invention offers an improved capacity for communication systems employing a high speed link capacity with low associated signal processing complexity.

SUMMARY OF THE INVENTION

One form of the present invention is a method of operating a transceiver including one or more transmitter antennas, at least one receiver antenna, and one or more propagation channels between the one or more transmitter antennas and the one or more receiver antennas. First, a binary stream assembled into groups of bits forming symbol indices is received by the transceiver. Second, the transceiver generates at least one complex

symbol value in response to a reception of the binary stream with each one complex symbol value being normalized over one or more channel coefficients associated with the propagation channel(s). Thereafter, one of the receiver antennas is selected to receiver the at least one complex symbol value from the transmitter antenna(s). In one aspect, the selection of the receiver antenna is a function of a metric proportional to an average injection power corresponding to the selected receiver antenna. In another aspect, the selection of the receiver antenna is a function of a vector norm corresponding to the selected receiver antenna.

The foregoing form as well as other forms, features and advantages of the invention will become further apparent from the following detailed description of the presently preferred embodiment, read in conjunction with the accompanying drawings. The detailed description and drawings are merely illustrative of the invention rather than limiting, the scope of the invention being defined by the appended claims and equivalents thereof.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates a block diagram of one embodiment of an adaptive vector modulation transceiver in accordance with the present invention;

FIG. 2 illustrates a block diagram of a first embodiment of a spatial mapping module and a first embodiment of a receiver of the **FIG. 1** adaptive vector modulation transceiver;

FIG. 3 illustrates a flowchart representative of a first embodiment of a receiver antenna selection method in accordance with the present invention;

FIG. 4 illustrates a flowchart representative of a second embodiment of a receiver antenna selection method in accordance with the present invention;

FIG. 5 illustrates a block diagram of a second embodiment of a spatial mapping module of the **FIG. 1** adaptive vector modulation transceiver; and

FIG. 6 illustrates a block diagram of a second embodiment of a receiver of the **FIG. 1** adaptive vector modulation transceiver.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

FIG. 1 illustrates one embodiment of an adaptive vector modulation (AVM) system transceiver **10** (hereinafter "AVM transceiver **10**") in accordance with the present invention. A transmitter of the AVM transceiver **10** includes a symbol modulator **20** and a spatial mapping module **30**. The symbol modulator **20** receives as an input a binary information stream assembled into groups of K bits forming symbol indices J. In response thereto, the symbol modulator **20** conventionally provides a generally complex-valued Quadrature Amplitude Modulation (QAM) symbol s_J in the form of a member of any well-known constellation (e.g., 16-QAM, 64-QAM, etc.). The spatial mapping module **30** receives the modulation symbol s_J, and in response thereto, the spatial mapping module **30** generally directs a transmission of M_T complex symbol values (not shown) from each of M_T transmitter antennas where $1 \leq M_T$. In the embodiment of **FIG. 1**, $M_T = 3$ whereby spatial mapping module **30** specifically directs a transmission of three (3) complex symbol values (not shown) from a transmitter antenna **TX_0**, a transmitter antenna **TX_1** and a transmitter antenna **TX_2**, respectively.

The transmitted complex symbol values are received by one of M_R receiver antennas where $1 \leq M_R$, and M_T and M_R may or may not have identical values. In the embodiment of **FIG. 1**, $M_R = 3$ whereby the transmitted complex symbol values are received by one of a receiver antenna **RX_0**, a receiver antenna **RX_1**, and a receiver antenna **RX_2**. The complex symbol values transmitted from each transmitter antenna **TX_0- TX_2** are weighted versions of modulation symbol s_J where the weights are a function of the receiver antenna among the receiver antennas **RX_0- RX_2** selected to receive the complex symbol values, and the propagation channels between the M_T transmitter antennas and the M_R candidate receiver antennas. The

result is a normalization of the complex symbol values over the channel coefficients associated with the propagation channels.

Upon reception of the complex symbol values by the selected receiver antenna, the receiver **40** demodulates the complex symbol values to recover an estimate of the modulation symbol s_J to thereby generate an estimate of the transmit symbol index J to obtain the binary information sequence input to the symbol modulator **20**.

The symbol modulator **20**, the spatial mapping module **30**, and the receiver **40** may be implemented in hardware (analog or digital), software, or any combination of hardware and software. From a subsequent description of various embodiments of the spatial mapping module **30** and the receiver **40**, those having ordinary skill in the art will appreciate a sequential operation of the components of the symbol modulator **20**, the spatial mapping module **30**, and the receiver **40** (e.g., in a software implementation) and a concurrent operation of the symbol modulator **20**, the spatial mapping module **30**, and the receiver **40** (e.g., in a hardware implementation).

FIG. 2 illustrates a spatial mapping module **30a** (for the particular case of $M_T = 3$) as one embodiment of the spatial mapping module **30** (**FIG. 1**) and a receiver **40a** as one embodiment of the receiver **40** (**FIG. 1**). In response to the modulation symbol s_J, and selection of the i-th receiver antenna, the spatial mapping module **30a** generates a complex symbol value x_0, a complex symbol value x_1, and a complex symbol value x_2 in accordance with the following general equation [1]:

$$x_m = \frac{\sqrt{E_s}(h_{i,m}^*)}{\sum_{j=0}^{M_T-1} |h_{i,J}|^2} s_J \quad m = 0,1,\cdots,M_T - 1 \qquad [1]$$

where E_s is a desired mean received symbol energy, M_T is the number of transmitter antennas ($M_T = 3$ for the spatial mapping module **30a**), and $h_{i,j}$ is a complex-valued channel coefficient.

For this particular implementation, the complex-valued baseband-equivalent channels connecting the transmitter antennas **TX_0- TX_2** with each of the receiver antennas **RX_0- RX_2** is assumed to comprise a single coefficient (conventionally referred to as a 'flat' channel). Accordingly, there are $M_R \times M_T$ distinct channel coefficients. In one embodiment, the channel coefficients are organized into a matrix L_1 having M_R rows (or groups) of M_T coefficients (equivalently, M_R length-M_T row vectors) in accordance with the following equation [2]:

$$L_1 = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,M_T} \\ h_{2,1} & h_{2,2} & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ h_{M_R,1} & \cdots & \cdots & h_{M_R,M_T} \end{bmatrix} = \begin{bmatrix} \mathbf{h}_1 \\ \mathbf{h}_2 \\ \vdots \\ \mathbf{h}_{M_R} \end{bmatrix} \qquad [2]$$

where each group comprises the M_T channel coefficients connecting the transmitter antennas **TX_0- TX_2** to one of the receiver antennas **RX_0- RX_2**.

A transmission of the complex symbol value x_0, the complex symbol value x_1, and the complex symbol value x_2 from the transmission antennas **TX_0-TX_2**, respectively, is directed along a subset of the channel coefficients of equation [2] in accordance with the antenna selection method of the present invention.

FIG. 3 illustrates a flowchart **50** representative of one embodiment of a receiver antenna selection method. During a stage **S52** of the flowchart **50**, a metric proportional to the average injection power (AIP) (where the averaging

process is defined with respect to the transmitted symbol process – whose component symbols may not have constant energy – and assumes the fading channel coefficients are approximately constant for a particular interval) corresponding to selection of the i-th (of M_R) candidate receiver antennas is computed in accordance with the following equation [3]:

$$AIP_i = \frac{1}{\sum_{j=0}^{M_T-1} \left| h_{i,j} \right|^2} \qquad [3]$$

During a stage **S54** of the flowchart **50**, the receiver antenna (selected over index i) having the smallest average injection power metric AIP_i is selected, and that receiver antenna is then used to receive the complex symbol value x_0, the complex symbol value x_1, and the complex symbol value x_2 after implicit processing by the corresponding selected channel coefficient vector $\mathbf{h}_i$ according to the definitions of equation [2].

FIG. 4 illustrates a flowchart **60** representative of another embodiment of a receiver antenna selection method. During a stage **S62** of the flowchart **60**, the L_2 vector norm (VN) of the row vector $\mathbf{h}_i$ corresponding to each of the M_R candidate receiver antennas is computed in accordance with the following equation [4]:

$$VN_i = \sum_{j=0}^{M_T-1} \left| h_{i,j} \right|^2 = \left\| \mathbf{h}_i \right\|_2^2 \qquad [4]$$

During a stage **S64** of the flowchart **60**, the channel having the highest vector norm VN_i is selected, and the corresponding i-th receiver antenna is used to receive the complex symbol value x_0, the complex symbol value x_1, and the complex symbol value x_2 after implicit processing by the corresponding selected channel coefficients $\mathbf{h}_i$.

In one embodiment, the spatial mapping module **30a** executes either the flowchart **50** or the flowchart **60**, and communicates the receiver antenna selection to a switch **41** of the receiver **40a**. In a second embodiment, the switch **41** executes either the flowchart **50** or the flowchart **60**, and communicates the receiver antenna selection to the spatial mapping module **30a**. In a third embodiment, both the spatial mapping module **30a** and the switch **41** execute either the flowchart **50** and/or the flowchart **60**, and handshake as to the receiver antenna selection.

In response to the receiver antenna selection, the switch **41** establishes a communication between the receiving antenna associated with the selected channel and a slicer **42** (which could equivalently be termed a hard-decision symbol estimator). For example, upon a selection of the channel 1, the switch **41** establishes a communication between the receiving antenna **RX$_1$** and the slicer **42** as exemplary illustrated in **FIG. 2**. The slicer **42** receives a modulation signal $\hat{s}_J$ that is an estimation of modulation signal s_J. In response thereto, the slicer **42** conventionally generates a group of bits $\hat{J}$ as an estimate of the symbol index J (**FIG. 1**).

The description above was particularly intended for use in channels where each channel coefficient comprises a single complex-valued coefficient. The invention can be extended to include so-called frequency-selective channels (i.e., where the channel comprises a non-zero length time-series of complex-valued coefficients).

FIG. 5 illustrates a spatial mapping module **30b** as another embodiment of spatial mapping module **30** (**FIG. 1**). The spatial mapping

module **30b** is an extension of the present invention to frequency-selective channels using the well-known technique of Orthogonal Frequency Division Modulation (OFDM). In response to a length-N sequence of modulation symbols s_J, a serial to parallel converter **31** conventionally concatenates the N modulation symbols s_J into a group of modulation symbols $s_J[0],\cdots,s_J[N-1]$. A spatial mapper **32** provides a group of complex symbol values $X_0[0],\cdots,X_0[N-1]$, a group of complex symbol values $X_1[0],\cdots,X_1[N-1]$ and a group of complex symbol values $X_2[0],\cdots,X_2[N-1]$ as a function of modulation symbols $s_J[0],\cdots,s_J[N-1]$.

In one embodiment, given the selection of the i-th receiver antenna, the spatial mapper **32** generates complex symbol values $X_0[0],\cdots,X_0[N-1]$, complex symbol values $X_1[0],\cdots,X_1[N-1]$ and complex symbol values $X_2[0],\cdots,X_2[N-1]$ in accordance with the following equation **[5]**:

$$X_j[k] = \frac{\sqrt{E_s}\,(H_{i,j}^{*}[k])}{\sum_{m=0}^{M_T-1} \left|H_{i,m}[k]\right|^2} s_J[k] \qquad k=0,1,\cdots,N-1;\ j=0,1,\cdots,M_T-1 \tag{5}$$

[5]

where $H_{i,j}[k]$ is generally the single frequency-domain complex-valued channel coefficient corresponding to the k-th (of N) OFDM sub-channel connecting the j-th transmitter antenna to the i-th receiver antenna.

An inverse Fast Fourier Transform **33a** ("IFFT **33a**') conventionally transforms the group of frequency-domain complex symbol values $X_0[0],\cdots,X_0[N-1]$ into a group of time-domain complex symbol values

$x_0[0],\cdots,x_0[N-1]$. A parallel/serial converter **34a** conventionally converts the group of time-domain complex symbol values $x_0[0],\cdots,x_0[N-1]$ into a time-domain complex symbol sequence denoted $\mathbf{x_0}$. A cyclic redundancy module **35a** conventionally adds a cyclic prefix and/or cyclic postfix to the time-domain complex symbol sequence $\mathbf{x_0}$ to yield a time-domain complex symbol sequence z_0.

An IFFT **33b** conventionally transforms the group of frequency-domain complex symbol values $X_1[0],\cdots,X_1[N-1]$ into a group of time-domain complex symbol values $x_1[0],\cdots,x_1[N-1]$. A parallel/serial converter **34b** conventionally converts the group of time-domain complex symbol values $x_1[0],\cdots,x_1[N-1]$ into a time-domain complex symbol sequence $\mathbf{x}_1$. A cyclic redundancy module **35b** conventionally adds a cyclic prefix and/or cyclic postfix to the time-domain complex symbol sequence $\mathbf{x}_1$ to yield a time-domain complex symbol sequence z_1.

An IFFT **33c** conventionally transforms the group of frequency-domain complex symbol values $X_2[0],\cdots,X_2[N-1]$ into a group of time-domain complex symbol values $x_2[0],\cdots,x_2[N-1]$. A parallel/serial converter **34c** conventionally converts the group of time-domain complex symbol values $x_2[0],\cdots,x_2[N-1]$ into a time-domain complex symbol sequence $\mathbf{x}_2$. A cyclic redundancy module **35c** conventionally adds a cyclic prefix and/or cyclic postfix to the time-domain complex symbol sequence $\mathbf{x}_2$ to yield a time-domain complex symbol sequence z_2.

The cyclic prefixes and/or cycle postfixes added to time-domain complex symbol sequences $\mathbf{x}_0 - \mathbf{x}_2$ are determined by factors such as, for example, a maximum channel time-dispersion.

FIG. 6 illustrates an OFDM receiver **40b** as another embodiment of the receiver **40** (**FIG. 1**). The switch **41** can operated as previously described herein in connection with the flowchart **50** (**FIG. 3**) with the metric proportional to the average injection power (AIP) (where averaging is again defined with respect to the transmitted symbol process, for a set of channel coefficients assumed constant over an interval) corresponding to each candidate (i-th) receiver antenna computed in accordance with the following equation [7]:

$$AIP_i = \sum_{k=0}^{N-1}\left(\frac{1}{\sum_{j=0}^{M_T-1}\left|H_{i,j}[k]\right|^2}\right) \qquad [7]$$

Alternatively, the switch **41** can operated as previously described herein in connection with the flowchart **60** (**FIG. 4**) with the vector norm VN of the channel corresponding to the i-th receiver antenna is computed in accordance with the following equation [8]:

$$VN_i = \sum_{k=0}^{N-1}\left(\sum_{j=0}^{M_T-1}\left|H_{i,j}[k]\right|^2\right) = \sum_{k=0}^{N-1}\left\|\mathbf{H}_i[k]\right\|_2^2 \qquad [8]$$

where – in a manner similar to equation [2] – the row vector $\mathbf{H}_i[k]$ is defined as the length-M_T vector comprising

$\mathbf{H}_i[k] = \left[H_{i,0}[k] \quad H_{i,1}[k] \quad \cdots \quad H_{i,M_T}[k]\right]$.

A cyclic redundancy module **42** receives a time-domain complex symbol sequence $\mathbf{z}_\mathbf{r}$, and in response thereto, conventionally removes the cyclic prefix and/or the cyclic postfix to yield a time-domain complex symbol sequence $\mathbf{x}_\mathbf{r}$. A serial/parallel converter **43** conventionally converts the time-domain complex symbol sequence $\mathbf{x}_\mathbf{r}$ into a group of time-domain complex symbol values $x_r[0],\cdots,x_r[N-1]$. A Fast Fourier Transform **44** ("FFT **44**") conventionally transforms the time-domain complex symbol values $x_r[0],\cdots,x_r[N-1]$ into a group of frequency-domain complex symbol values $\hat{s}_J[0]-\hat{s}_J[N-1]$. A parallel/serial converter **45** conventionally converts the frequency-domain complex symbol values $\hat{s}_J[0]-\hat{s}_J[N-1]$ into a set of N estimated modulation symbols $\hat{s}_J$ that is an estimate of modulation symbols s_J (**FIG. 1**). The slicer **46** conventionally generates N symbol index estimates $\hat{J}$ each identifying K bits (**FIG. 1**).

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrative and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes that come within the meaning and range of equivalency of the claims are to be embraced within their scope.